ELASTOMER UNISTRUCTURE INSULATORS*

L. P. Bradley and E. L. Orham
University of California
Lawrence Livermore National Laboratory
P.O. Box 5508, Livermore, CA 94550

R. L. Anderson
American Controls, Inc.
Box 22535, San Diego, CA 92122.

Summary

A single elastomer high voltage dielectric provides low inductance interconnection of capacitors, railgaps, and vacuum load. It complies against conductors to prevent tracking. Operation below a threshold breakdown field, provides long lifetime.

Introduction

The Nova laser system[1] being developed at LLNL for inertial confinement fusion experiments contains 20 parallel laser amplifier chains. We are realizing a significant cost saving ($1M/chain) by replacing the traditional Faraday rotator-polarizer with a plasma shutter[2,3] to protect the laser from target reflected light.

The plasma shutter contains a foil which is exploded in a railgun geometry and is driven across the optical beam path by a 1 MA current rising at $5x10^{12}$ A/sec. The utilization of such a pulse power source in a laser system has presented some unique design constraints. The system must be self-contained, compact, exceedingly reliable, and EMI free.

To produce a low-inductance pulser that meets the foregoing requirements, we have developed and characterized a single silicone insulator.[4] This thin coaxial insulator reduces the number of joints and exposed edges. It compresses against components to prevent arcing. Its elasticity enables it to bounce back after a magnetically induced impulse to restore contact against the main conductors.

The main features of the elastomer insulator is its high dielectric strength and a high threshold field below which the probability of failure is small. This elastomer is tough, flexible, and can be molded into complex shapes of close tolerance and fine detail. In some cases, order-of-magnitude improvement of high voltage surface creep (as contrasted with standard technology) is achieved.

Other features of the silicone insulator are that it seals a vacuum interface, the load being in vacuum, and it gaskets against a replaceable chip which carries the foil to be exploded (the chip subassembly is automatically replaced in vacuum after each shot).

An isometric cross sectional view of the 70x70x150 cm plasma shutter pulser is shown in Fig. 1. A more detailed cross sectional view is shown in Fig. 2, revealing the interconnection between the capacitor, railgap switch, and load (chip). A photograph of the 3 mm thick by 70x70 cm shaped silicone insulator is shown in Fig. 3.

The dielectric failure modes may be categorized as: punch through (bulk-breakdown), surface tracking under a dielectric obstacle (track-under), and surface tracking across a free surface (track-over).

We shall discuss the unistructure elastomer insulator using the Nova plasma shutter pulser and its silicone insulator as illustrative.

Bulk Breakdown

We have measured the breakdown characteristics of elastomer sheet stock by placing it between the ends of cylindrical electrodes. These electrodes were surrounded by a solid (compressed polyurethane) or liquid (freon) for DC shots, and liquid (water) for pulsed tests. The pulse waveform was either 10 ns rise/10 μs fall or a damped sinusoid with 600 μs half period and 80% reversal. The latter condition simulated the expected plasma shutter environment.

Several elastomer materials were tested,[4] but herein we shall only discuss data obtained for Dielectric Sciences 5250 molded silicone. These data were taken for 5 cm diameter electrodes, with all breakdowns occurring in the uniform field region.

The data were plotted on Weibull paper with coordinates of fraction failed F_e, and breakdown field E_b. The data tended to curve downward at low breakdown field, indicating a finite minimum breakdown field E_o. By iteratively replotting the data for $E_b - E_o$ until we obtained a straight line, we established the value of the minimum breakdown field, E_o. The best fit of the data provided the relation of fraction failed F_e, and breakdown field E_b as

$$F_e = 1 - \exp - \left(\frac{E_b - E_o}{E_m} \right)^{\alpha}$$

where, for 5250 at 1.5 mm thickness,
Minimum breakdown field E_o = 0.61 MV/cm.
Median breakdown field E_m = 1.12 MV/cm.
Slope α = 4.7

There was negligible variation with the rate of application of the voltage.

With the pulsed data, for a unipolarity waveform, the results were identical. For the voltage reversal pulsed waveform, the result showed that the peak to peak field at breakdown was equal to the unipolar

*Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory uner contract No. W-7405-ENG-48.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **JUN 1981**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Elastomer Unistructure Insulators**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of California Lawrence Livermore National Laboratory P.O. Box 5508, Livermore, CA 94550**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002371. 2013 IEEE Pulsed Power Conference, Digest of Technical Papers 1976-2013, and Abstracts of the 2013 IEEE International Conference on Plasma Science. Held in San Francisco, CA on 16-21 June 2013. U.S. Government or Federal Purpose Rights License.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**3**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

field at breakdown.

We obtained the same value of median breakdown field for several geometries and voltage waveforms, and this result leads us to conclude that we are measuring the true practical breakdown strength of the dielectric.

Compressed Contact

Elastomer insulators have been considered in the past[4,5] for compression against capacitor headers, and/or switches with a typical track-under field of $\lesssim$50 KV/cm. We have built upon these earlier studies to quantify contact area and pressure, and have achieved $\gtrsim$ 500 KV/cm. In a typical test set-up, we sandwiched the 0.3 cm thick silicone insulator between 1.3 cm thick aluminum and 2 cm thick plexiglas, with a thru-bolt. By compressing this assembly, we were able to visually identify an area of good contact. This simple first step led to mechanical and electrical requirements.

In comparison with deflection calculations, we established that the region of visual good contact corresponds to a definition of intimate contact. By performing electrical tracking tests using 25 μm thick aluminum foil electrodes sandwiched between the silicone and plexiglas, we established that the intimate region of contact has an order of magnitude higher tracking field than the contiguous region of poor contact. The tracking field is always high ($\gtrsim$500 KV/cm) or low ($\lesssim$50 KV/cm) depending on the region.

As the pressure on the thru-bolt was increased to 120 pounds, the intimate contact area increased monatonically to 4 cm diameter, and greater pressures did not increase the contact area. We thus established a clamping force and intrinsic associated contact area. Additionally, the softness (Durometer) of the elastomer did not particularly affect these results. The high-field performance could be improved beyond that described above by the application of a thin layer of void free silicone oil, but the details of this issue are beyond the scope of this report.

Surface Tracking

Surface tracking from a capacitor or switch electrode across the free surface of the silicone (ie. the surface not covered by an insulator) to some remote ground is a common problem. Such tracking may be partial as discharging the local micro-capacitance between the electrode and silicone or complete as discharging a track of surface capacitance between the electrode and ground. Both cases are illustrated in Fig. 4.

The DC case is rather straightforward. Provided the charge time is longer than the micro-capacitance surface discharge time, then surface tracking does not occur. Furthermore, the normal edge grading techniques are adequate.

Many factors affect the surface breakdown in the pulse case (typical with discharge) including local field enhancement and grading, voltage risetime, irriadiation (UV), polarity, surrounding gas and contamination. Guard barriers and destressing with total encapulsation are helpful but generally not adequate.

We have selected the simple technique of placing a thin sheet of paper between the metal electrode and ground, with the paper extending about 3 cm across the surface of the silicone. By using a laminate of black (construction), brown (craft), and white (bond) papers extending 1, 2, and 3 cm from the electrode respectively, effective grading for pulse discharge was achieved with no corona evident at 50 KV. Such surface treatment discharges the surface capacitance near the electrode, thereby preventing the initiation of a surface streamer. Additionally, such grading is an order of magnitude smaller than paper techniques normally used. We have established quality control techniques including radiograph and hipot of each insulator to insure reliability.

Conclusions

The elastomer insulator has been studied in detail with the philosophy that a single resiliant insulator could replace the multitude of insulators and joints normally used in pulse power systems. By treating each aspect of the dielectric separately and quantifying it, we have developed a reliable and simple insulator system. The bottom line is that such an insulator, although having a slightly lower breakdown field than normal solid insulator, when used according to the guidelines developed provides a more compact and lower inductance pulser system. Additionally, because of the intrinsic threshold breakdown field of an elastomer insulator, operation below this threshold provides exceedingly low probability of failure.

Two plasma shutter pulser modules have been constructed and extensively tested (one on the LLNL Shiva laser). These tests will continue for the next year prior to installation of 20 modules on Nova.

Acknowledgements

We appreciate the significant contributions of I. Stowers, J. Oicles, J. Goldlust, S. Faulkerson, J. Braucht, and R. Behymer.

References

1. R. O. Godwin, W. F. Hagen, J. F. Holzrichter, W. W. Simmons, and J. B. Trenholme, "Livermore builds a giant," Laser Focus 17, 58 (May 1981)
2. L. P. Bradley, E. L. Orham, I. F. Stowers, and P. Koert, "Development of a plasma retropulse shutter for Shiva and Nova," UCRL 52830 (Sept. 26, 1979)
3. I. F. Stowers and L. P. Bradley, "The Nova Plasma Shutter," p.9 Energy and Technology Review, UCRL 52000-81-5, (May 1981)
4. L. P. Bradley, E. L. Orham, I. F. Stowers, and J. R. Braucht, "Elastomer Dielectrics" for Pulse Power Conference on Electrical Insulation and Dielectric Phenomena, Boston (Oct. 26-29, 1980)
5. P. D'A Champney, Some recent advances in three electrode field enhanced triggered gas switches, Proc Conference Energy Storage, Compression, and Switching, p. 463, (November 5-7, 1974)

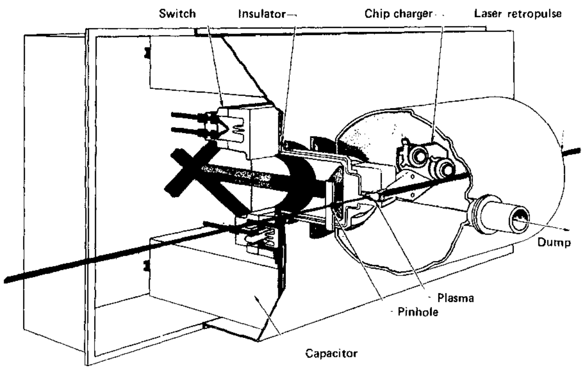

Figure 1
Cross section of Plasma Shutter Pulser

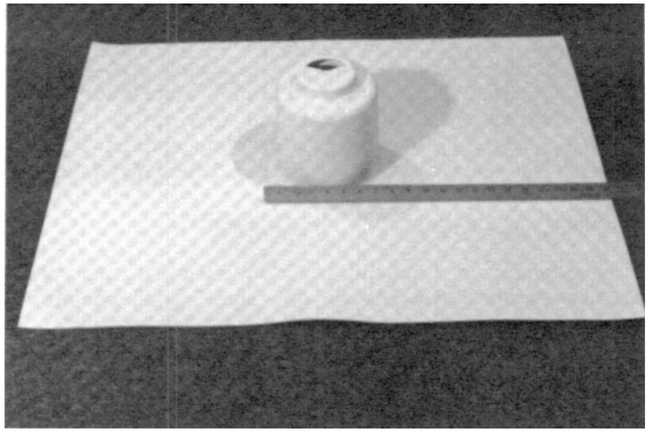

Figure 3
Photograph of plasma shutter molded silicone insulator

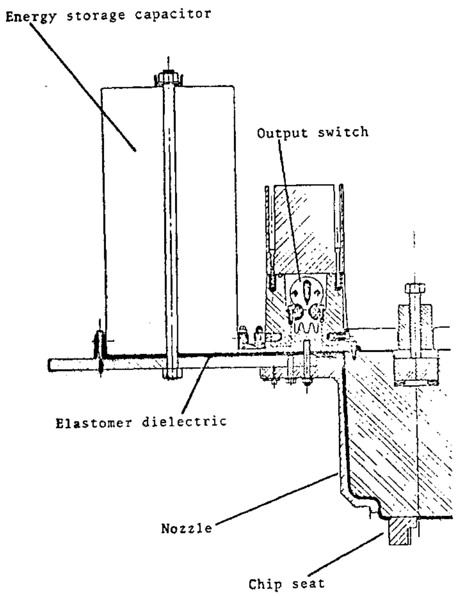

Figure 2
Assembly cross section of plasma shutter

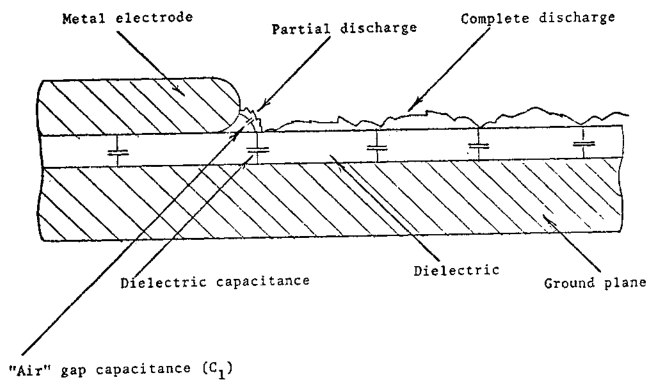

Figure 4
Equivalent circuit with typical surface discharge path for charged electrode above a sheet silicone insulator and ground plane